Impact of cloud cover on solar radiative biases and a simple parameterization for GCMs

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Outline

- A new simple methodology for using cloud resolving model data to systematically quantify the effect of anvil Cloud Cover (CC) on radiative biases.

- Simple parameterization of solar zenith angle effects of increasing "apparent" cloud cover

- Results of parameterization in ECMWF radiation scheme using CLOUDNET radar data cloud masks

Problem

- Want to investigate SW radiative biases in different cloud scenes, in particular deep convection (likely to have largest biases?)

- 3D Cloud resolving model perhaps only current reliable cloud proxy (tricky for idealized models, lack of dimensions in remotely sensed scenes)

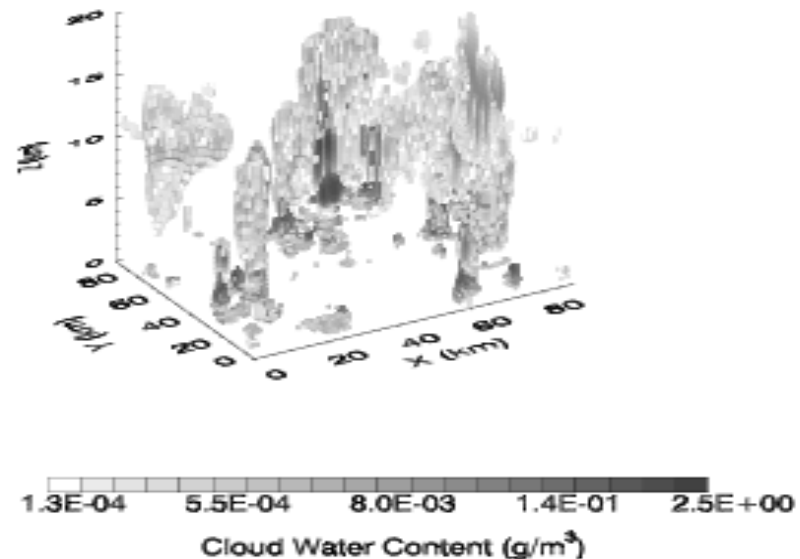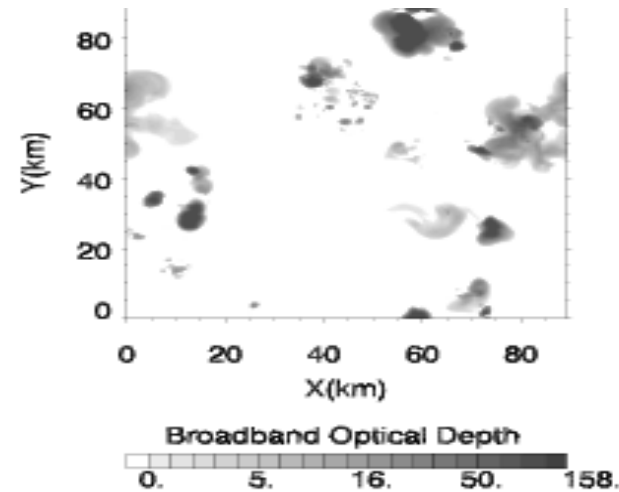- BUT! Difficult to systematically explore parameter space (control via boundary conditions, expensive…)

Approach

- Take a series of CRM cloud scenes and…

- …modify them by a simple idealized function!

- In this way, factors such as cirrus anvil coverage can be systematically controlled…

- …without sacrificing the realism of the cloud scene!

Input data

- We take output from Met Office LEM, run to radiative-convective equilibrium in the tropics

- 90 x 90 km domain, 50 vertical levels, 350m horizontal resolution

- Four separate scenes are modified in turn

Broadband Optical Depth

0.   5.   16.   50.   158.

1.3E-04   5.5E-04   8.0E-03   1.4E-01   2.5E+00

Cloud Water Content (g/m³)

CRM simulated scenes

Cloud Cover of CRM experiments controlled by equation

$$q_c = H(z-z_1)H(z_2-z)K\sin^2[(z-z_1)/(z-v_2)\pi] + q_l^{crm} + q_v^{crm} + q_i^{crm} - q_s^{crm}$$

Recipe:

1. Add idealized perturbation to total water at each level

2. Re-derive cloud water assuming no supersaturation exists

3. (Cook at -50°C and take cloud out of the oven after the tops are nicely glaciated!)

Exp-24:-1

Exp-24:0

Exp-24:1

Exp-24:2

Exp-24:3
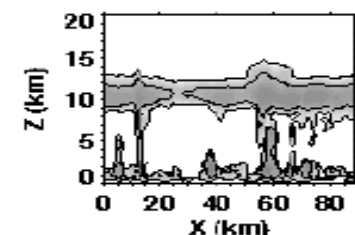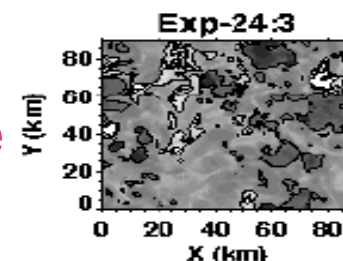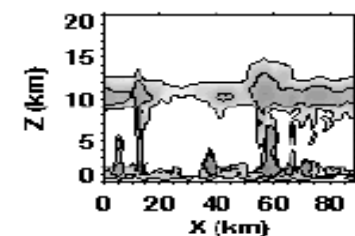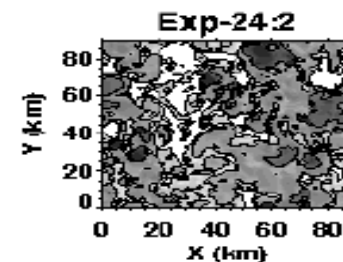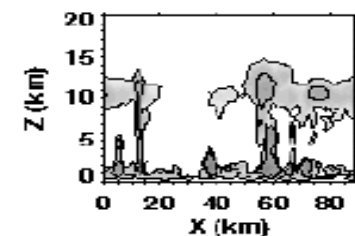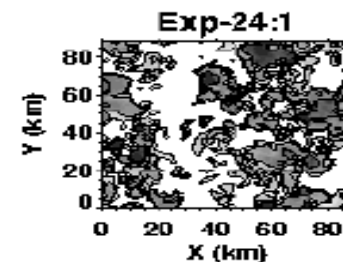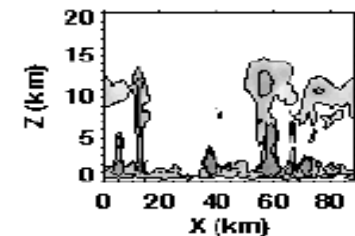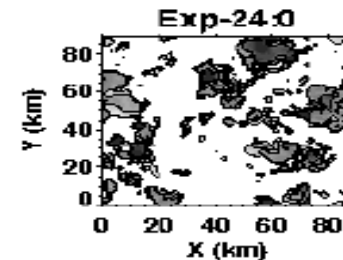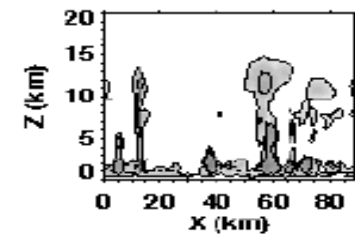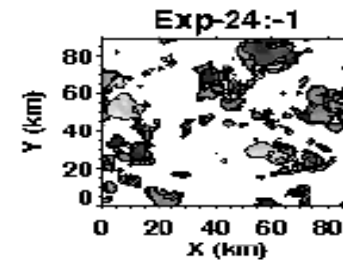
ICA bias as function of the cloud cover

- Two radiative calculations are performed: 3D and ICA using Montecarlo code (GRIMALDI)
- Strong dependence on cloud cover. From a zero bias for clear sky scene, the bias increases strongly to reach a maximum at 30 % CC
- The maximum value of the bias is around 20% when the sun is overhead but is larger when the sun is low
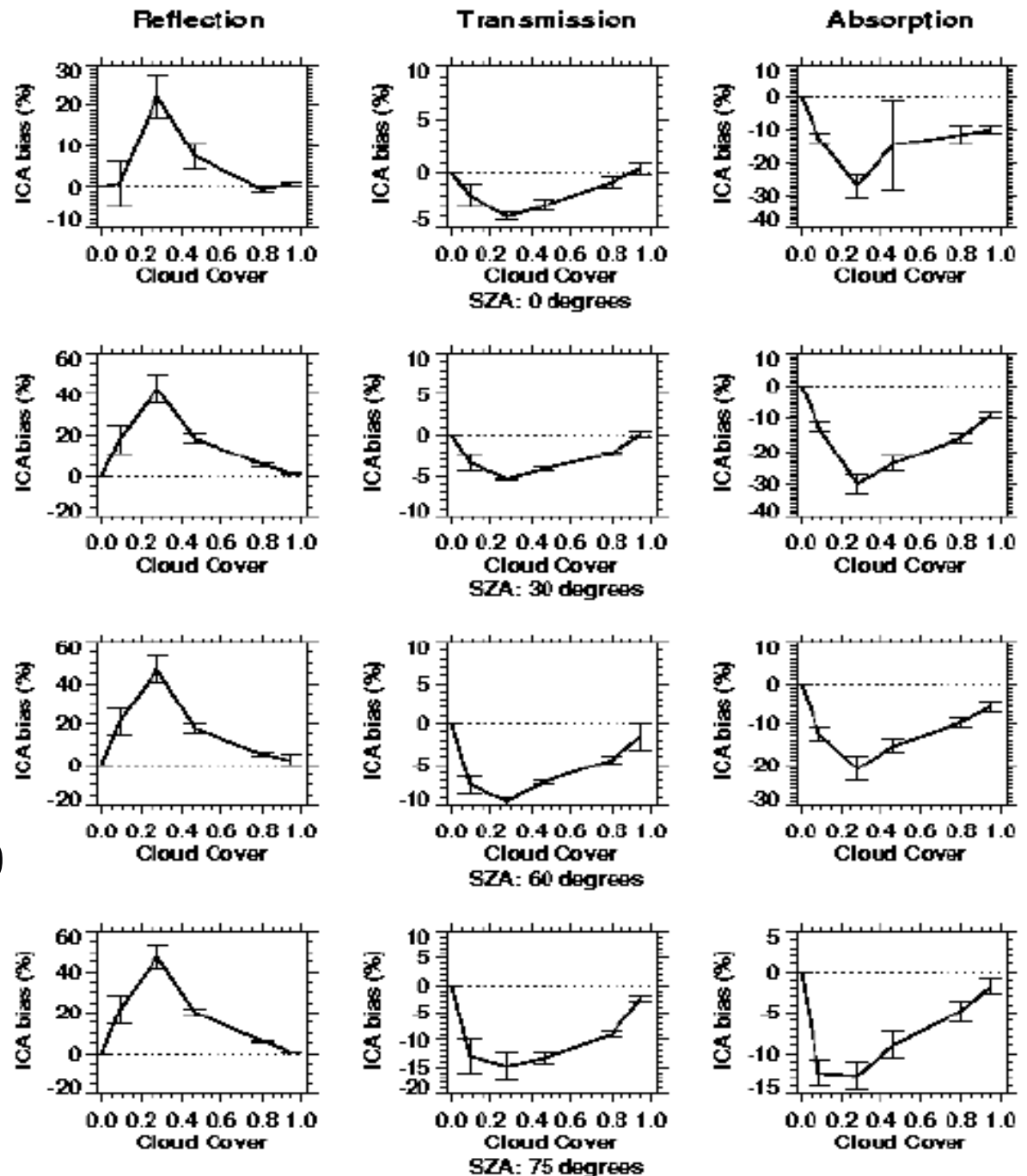
Effect of cloud number
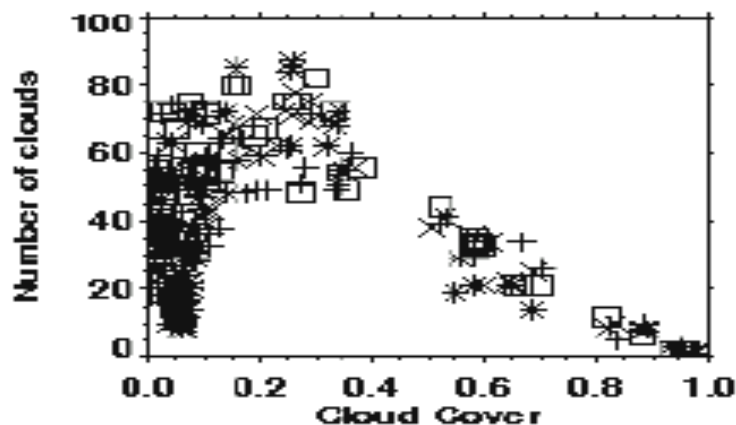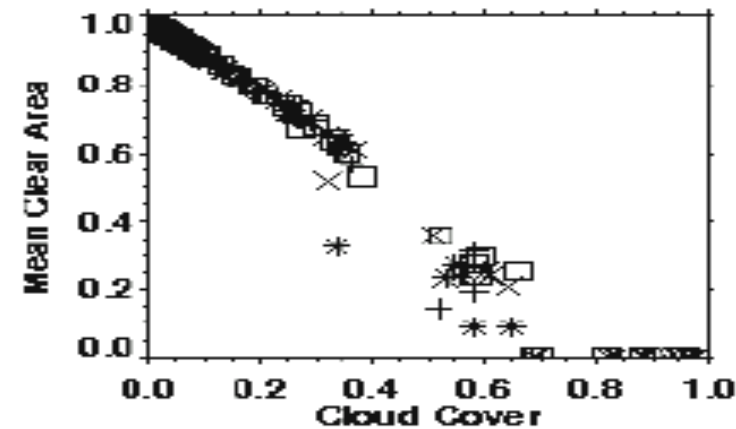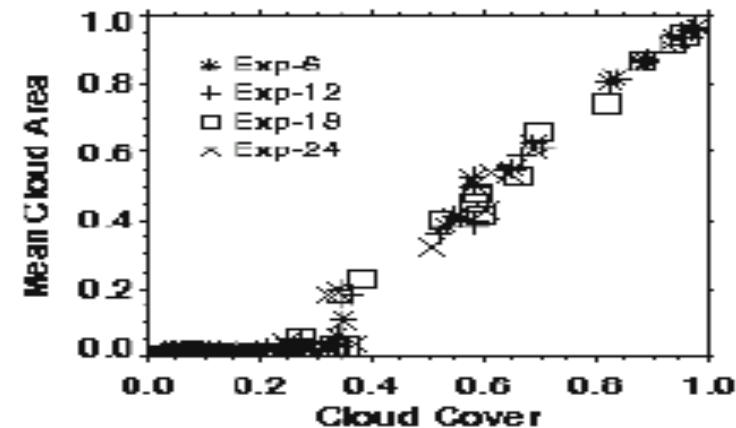
Why does the bias picks at 30 % cloud cover?

- For low cloud cover, the number of separate clouds increases with overall coverage. But cloud begin to form larger shields once cloud cover exceed 20 to 30%

- The asymmetric function matches the ICA bias, showing the bias is related to the number of cloud elements
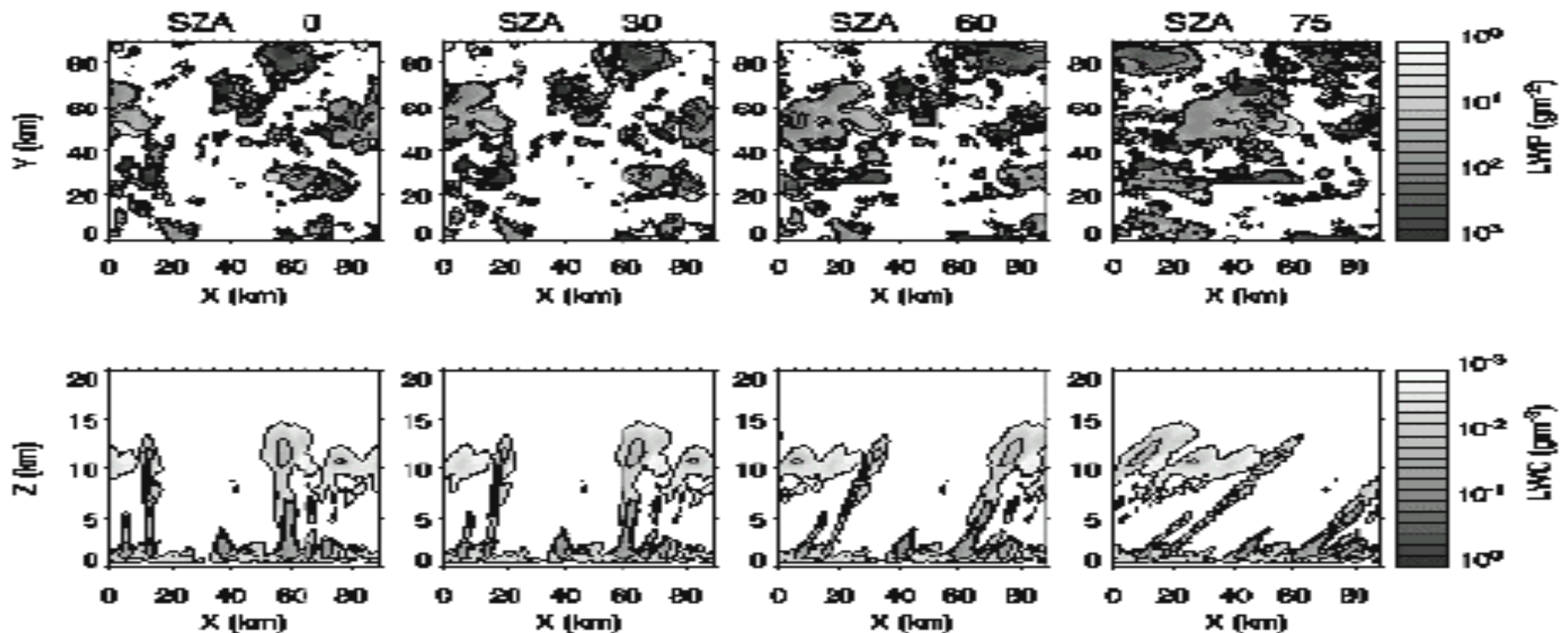
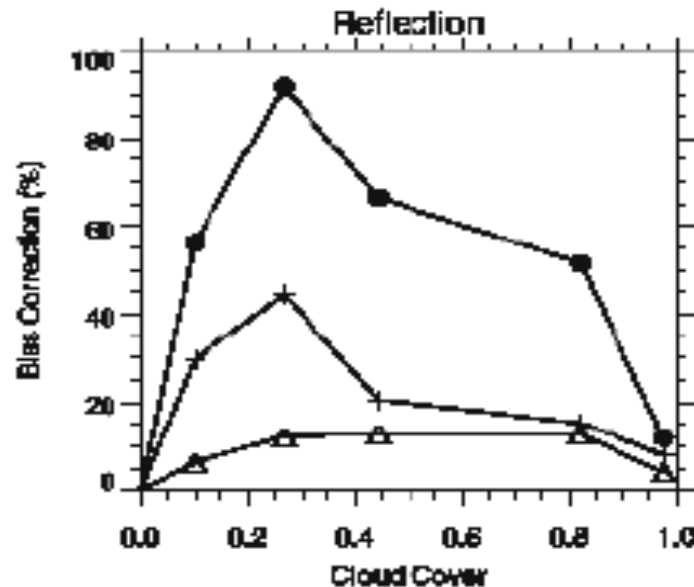# Bias Mechanisms

The bias is mainly controlled by two effects:

The increase in cloud cover due to the sun position

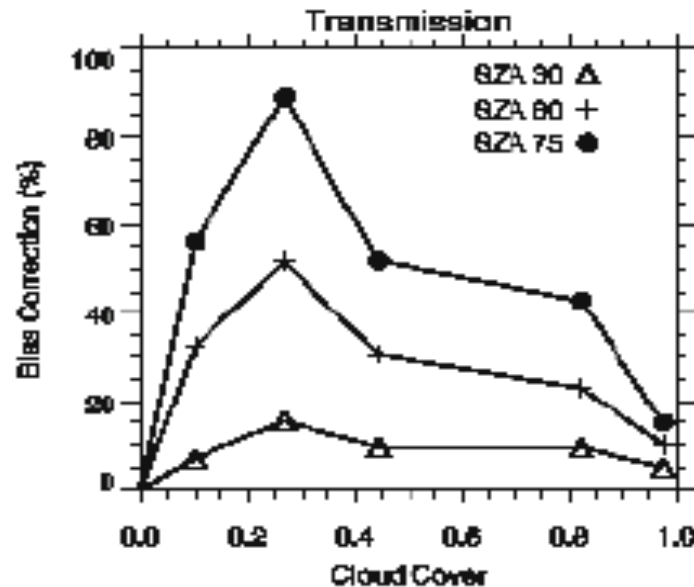The true 3D effect generated by photons scattered on a 3D plane

Correction for the first effect achieved simply by the use of a variant of the ICA calculation, the "tilted ICA" (see also Varnai and Davies)

Bias Correction

Reflection

Percentage correction to the ICA bias by the TICA approach

Transmission

SZA 30 △
SZA 60 +
SZA 75 ●

- Largest contribution to ICA bias <u>AT LOWER SUN ANGLES</u> derives from inexact cloud cover estimation performed by a 1D radiative calculation with broken clouds

- In a simple 1D calculation underestimates the cloud fraction. The error produced increases with solar declination angle and is largest when the cloud is small

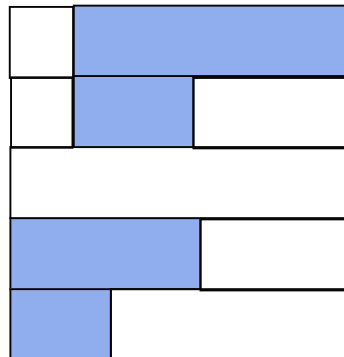- In fact, TICA corrects over 50% of the IPA Bias!!!

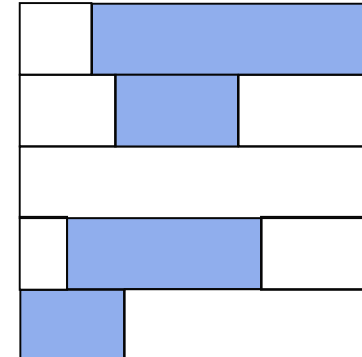# Framework for a GCM correction scheme

- We want to derive a method to account for CC increase as solar zenith angle decreases
- In GCM total cloud cover is determined by the overlap rule applied
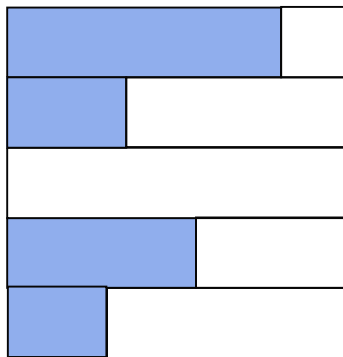
MAX   MAX-RANDOM   RANDOM

- Note that random overlap is resolution dependent

The use of decorrelation length to determine the CC

Hogan and Hillingworth (2002) suggested that a better overlap should be a combination of maximum and random overlap through the use of a decorrelation lengthscale

$$CC=\alpha CC_{max}+(1-\alpha)CC_{ran}$$

With

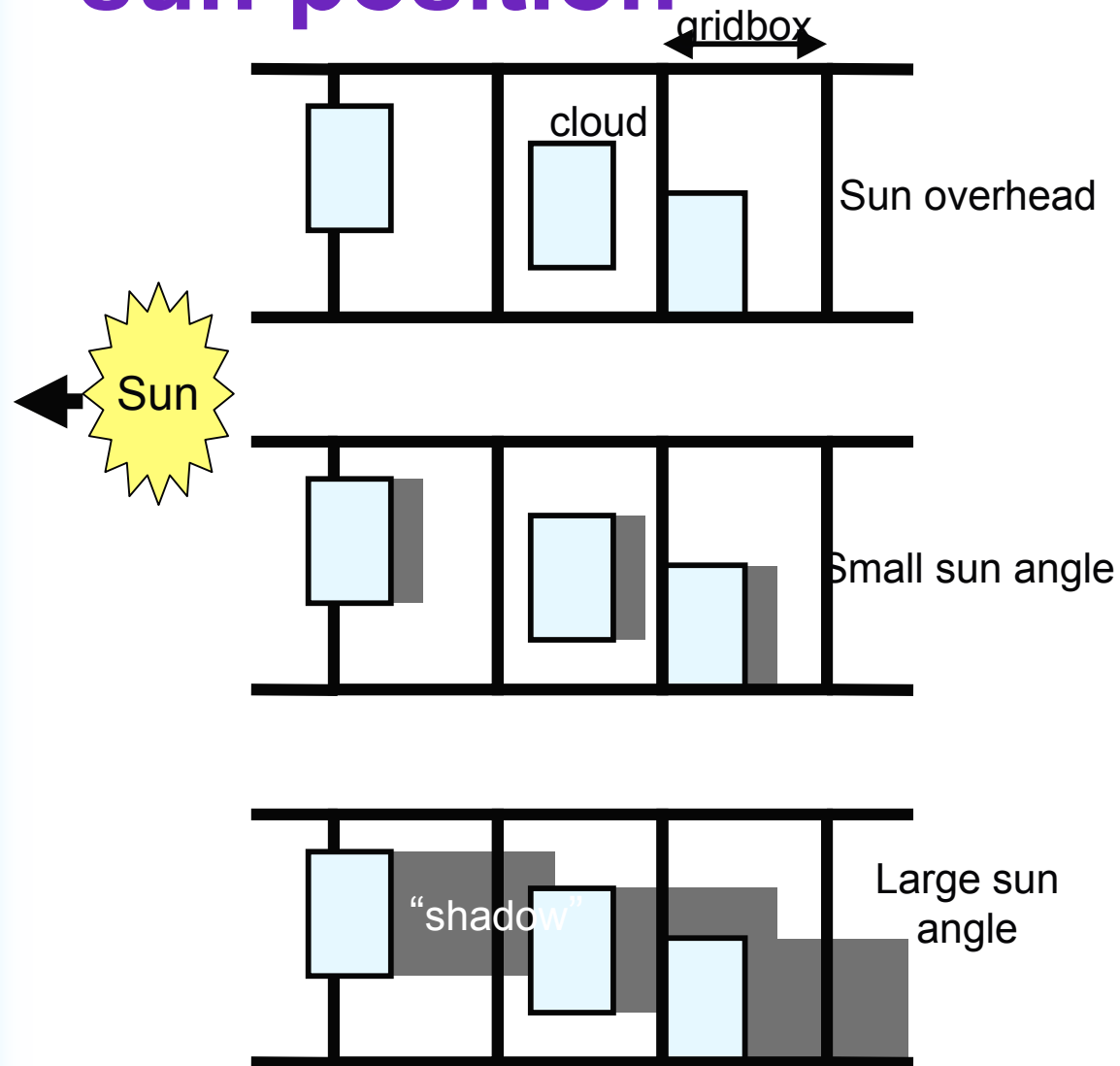 $\alpha=e^{-\Delta z/L}$

    $\Delta z=$ model resolution

    L = decorrelation length

In this way the CC is not resolution dependent
L = 0 random overlap
L= ∞ maximum overlap
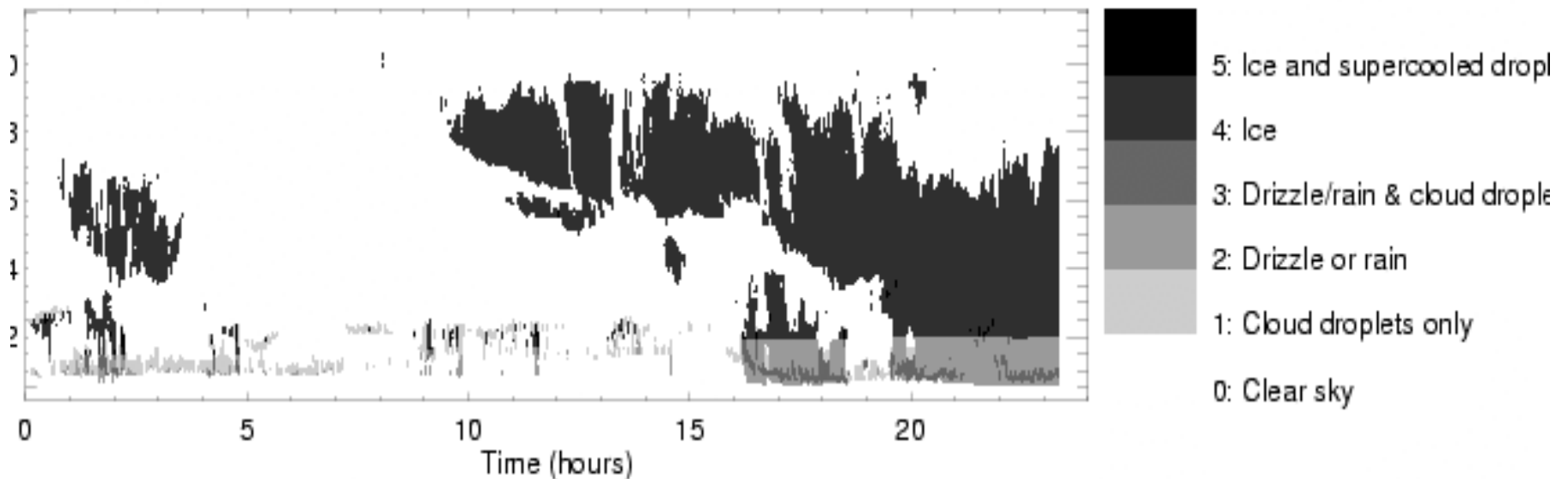
Changing in CC through the sun position

- At zenith the true cloud cover is obtained with the right choice of L_0
- At low sun angles the real cloud cover is determined by the horizontal correlation AXIOM 1: which we will assume random. Thus, $L \rightarrow 0$
- AXIOM 2: Transition between two regimes is related to the (cosine of the) SZA
- Thus, suggested parametrization:

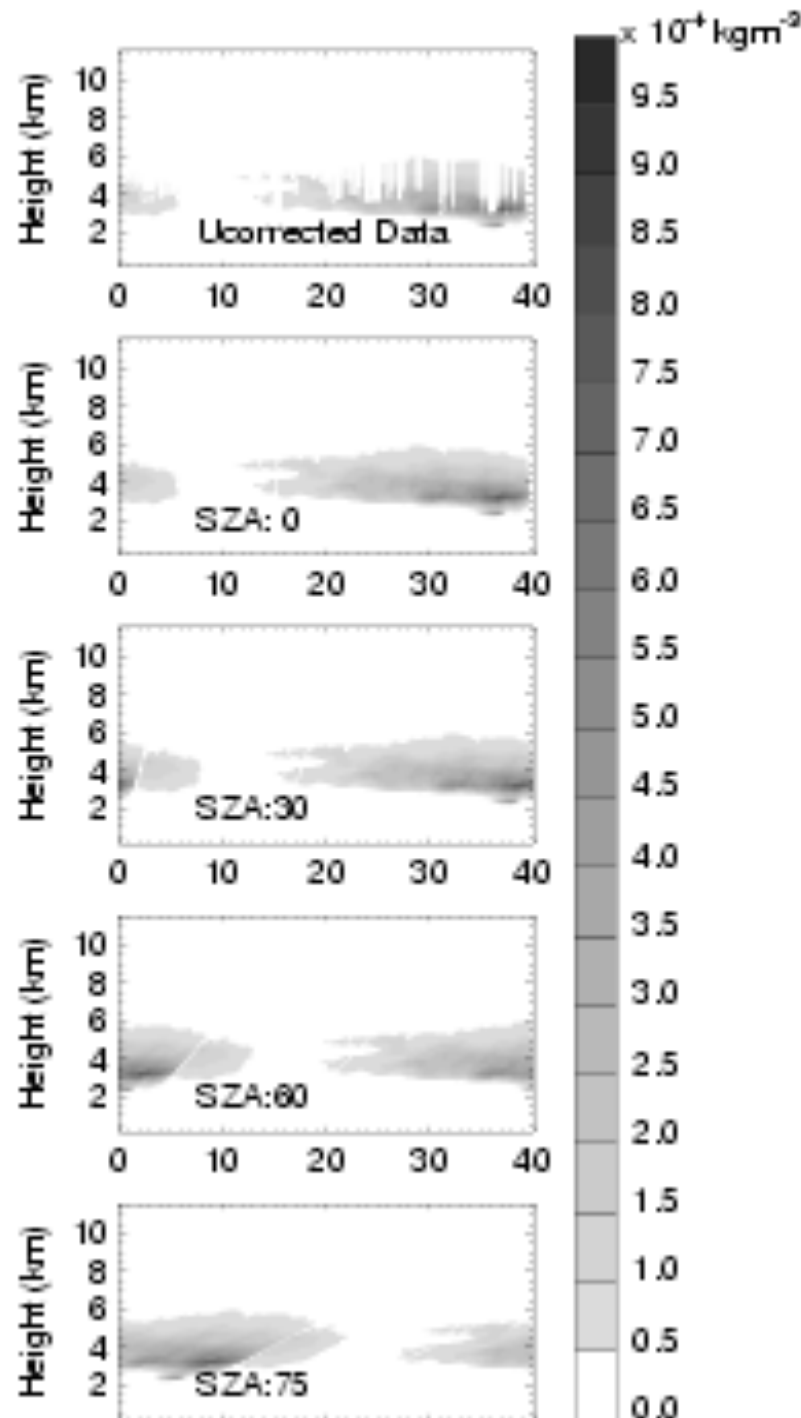$$L = L_0 \cos(SZA)$$

GIVEN THAT WE KNOW L_0

TEST for the suggested parameterization

RADAR data from Chilbolthon (UK) and Palasieau (F)

Total of 800 cloud scene have been analyzed

Split into legs of 40 km legs

5: Ice and supercooled dropl
4: Ice
3: Drizzle/rain & cloud drople
2: Drizzle or rain
1: Cloud droplets only
0: Clear sky

Courtesy of Robin Hogan through the CLOUDNET project
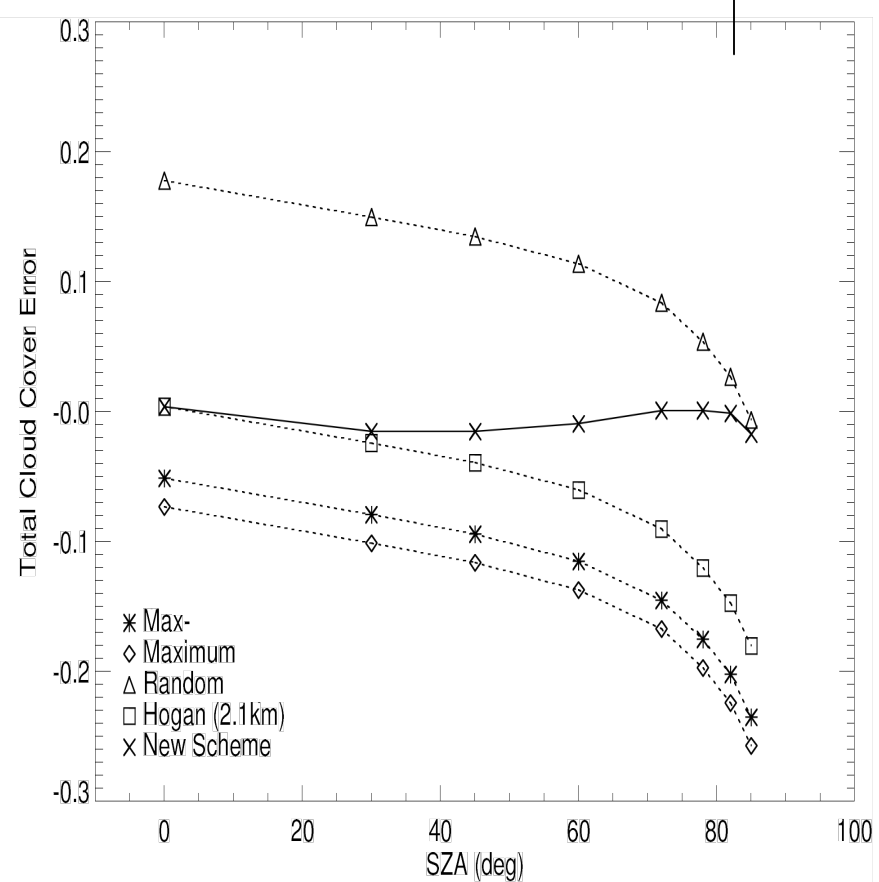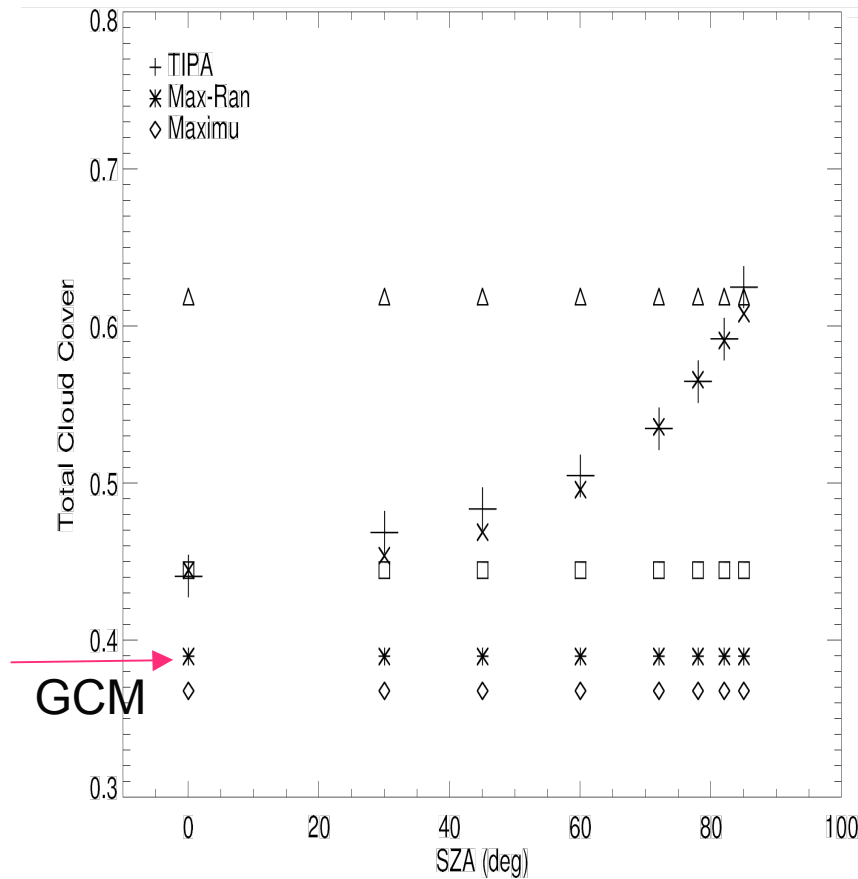
2D scene creation

- Data corrected to avoid spurious picks or rejected

- Shift applied to simulate the Tilted IPA

$$\Delta X = \Delta Z7 \ Tan(SZA)$$

- Total cloud cover calculated for:
  - Max Overlap
  - Ran Overlap
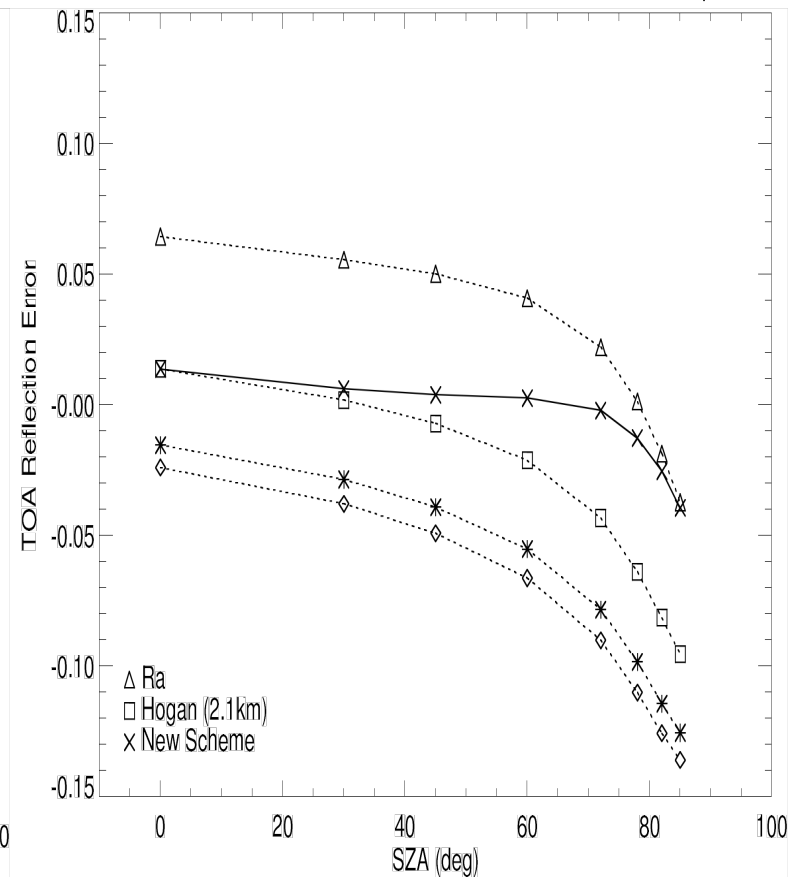 - Max-ran Overlap
  - Fix L_0
  - New scheme
  - TIPA (benchmark)
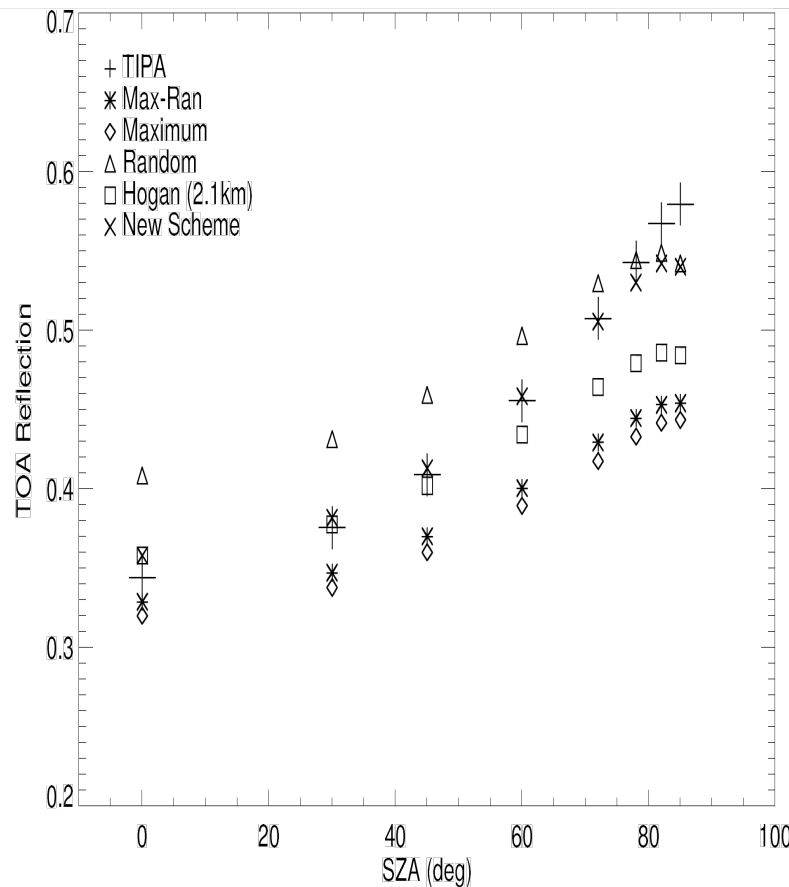
Apparent cloud cover
as a function of SZA

+ TRUE VALUE, * MAX-RAN, ∇ RAN, □ MAX, FIX L =2.1 km , x NEW scheme

+ TIPA, * MAX-RAN, ⊽ RAN, ⊠ MAX, ☐ FIX L =2.1 km , x NEW scheme

Effect of the new scheme on the BOA transmission (ECMWF rad scheme)
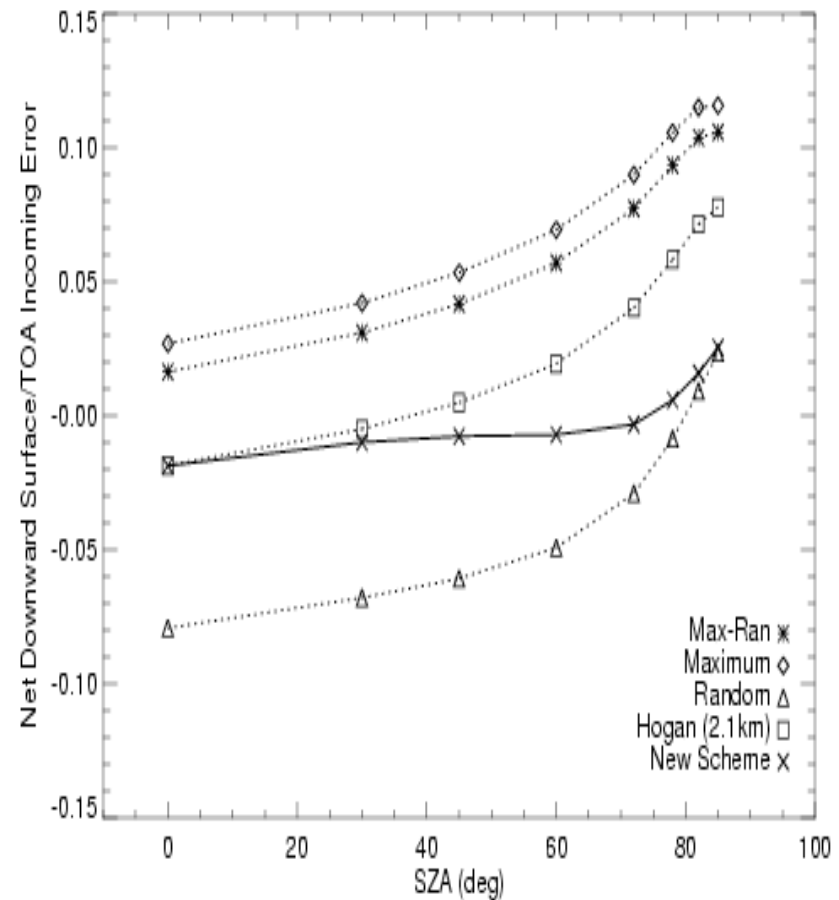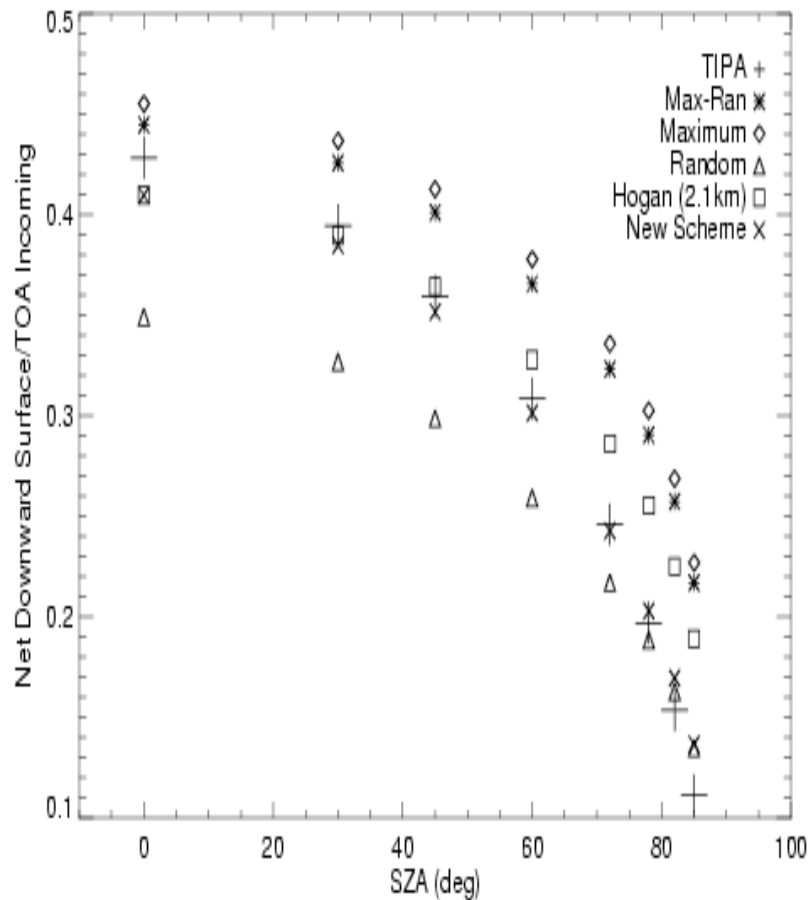
Conclusions

- ICA bias depend strongly on Cloud Cover (CC)

- The maximum ICA bias is found at 30% CC which correspond to the CC at which the maximum number of isolated clouds are present

- The ICA bias can be divided in two components:
    - The geometrical shading effects of cloud at low sun angles (>50% of error at low sun angles)
    - The true 3D photon scattering effect

- The TIPA approach corrects the first source of error

- Simple parametrization suggested which mimics the TIPA in a GCM, (overlap at low sun angles in random)

- Tests using TIPA and GCM calculations are v. promising! Apparent cloud cover increases reproduced, reflection too